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Sounding Rocket Delta Velocity System

EDWARD F. McKENNA

8 October 1976

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This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER:

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Chief Scientist

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A sounding rocket tumble system to enhance deceleration and redirect the flight path angle of a vehicle can be an effective means of accomplishing large spacial separation between a separated payload and the spent final stage rocket motor. The design and implementation of two such systems, for 9-in. - and 17-in. -diam payloads, is presented. Flight test results show that separation distances between payload and vehicle in the order of 10 percent of vehicle apogee can be achieved.

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Sounding Rocket Delta Velocity System

1. INTRODUCTION

Sounding rocket payloads separated from spent rocket motors in the exoatmosphere have always carried delta velocity systems to achieve some separation between the bodies. Usually these have been stored-energy systems of a mechanical or pneumatic nature that imparted a differential velocity between the bodies in the order of 1 to 3 m/sec. However, as the scientific requirements of ultra clean payloads become more common, it was recognized that greater spacial separation was necessary to avoid payload contamination by outgassing of a spent solid rocket motor or obstruction of optical viewing by separated bodies.

Mechanical or pneumatic spring energy systems are inherently low velocity devices due to the fact that their energy is delivered in a short time, resulting in intolerable accelerations on the separated payload if high velocity is to be achieved. A high velocity cold gas system would be expensive in dollars, volume, and weight. Auxiliary rocket engines can be used to accelerate the payload far from the final stage motor, but they are a possible source of payload contamination. This study looks at a different solution to the problem, that of decelerating the separated rocket motor to achieve considerable spatial separation.

(Received for publication 7 October 1976)

2. DECELERATION METHODS

A delta velocity system is a payload support system, and it is usually one of the less critical functions of the mission. Compared to say a sensor exposure mechanism or a sensor pointing device whose failure would result in total loss of data, failure of a delta velocity system would usually cause only partial data loss. Sensor contamination by rocket outgassing may mask some species of a composition measurement, or a hot rocket body may pass through the field of view of an IR detector during only part of the measuring time. Admittedly there may be some cases where the delta velocity system assumes a critical role, but that would be an unusual case. This fact, then, directly impacts the design criteria of a vehicle delta velocity system. The system must not degrade the reliability or prime mission objective in any way. It must not create an inordinate weight or volume penalty to the experimenter, and its cost must not be out of line with its intended benefit.

The goal of this study was to develop a system that would result in a spacial separation between payload and spent vehicle in the order of 10 percent of the payload apogee. An apparent solution would be the brute force approach; that is, employ retro rockets on the vehicle to decrease its velocity, thereby reducing the apogee and ground range, resulting in large spacial separations. However, for a typical 200-km apogee payload this would require a velocity decrease of over 1600 m/sec, and if a retro rocket were employed would mean about 9000 lb-sec of total impulse. The physical size of existing, surplus rocket motors of this class would impose too great a space and weight penalty on the prime mission to gain common acceptance.

A second method investigated was to separate the payload from the vehicle at a low altitude (<50 km) and to induce an upsetting moment into the vehicle in order to drastically increase its drag area, thereby reducing the velocity before the vehicle exits the atmosphere. Although this is feasible, the impact on payload design is considerable. A payload separated from the rocket motor at that low an altitude would require additional stability either in the form of aerodynamic stabilizers or a high power attitude control system. In addition to being costly, this solution would result in an increase in complexity and in an inherent decrease in reliability far beyond its anticipated benefit.

The method finally investigated and employed is a variation of the above. To insure no degradation of prime mission reliability, the payload would be separated from the final stage rocket motor just prior to exiting the atmosphere. This was defined by setting limits based on the predicted dynamic pressure (Q) on the payload. These limits were that Q be no greater than 8 psf and no less than 2 psf. A standard, stored energy, delta velocity device would initially separate the payload

from the rocket motor. Approximately 2 sec after separation a force would be applied at the head end of the rocket, perpendicular to the flight path angle at that time.

It was realized that due to the almost negligible air density at this altitude (60 to 70 km) very little deceleration due to drag could be expected, even if the motor was tumbled completely. However, a complete tumble would be an unlikely result in any event, because of the restoring moment generated by the vehicle fins even at that altitude. The expected result would be a vehicle coning to some degree about a slightly different flight path angle. Thus, some decrease in total velocity could be expected from the coning action and, combined with the redirection of the flight path angle, would result in significant spacial separation between the motor and the payload.

3. SYSTEM DESIGN

Two delta velocity system designs were generated. One, a 9-in.-diam cold gas unit, would be suitable for small rocket motors (Tomahawk, Hydac, etc.), and the second, a 17-in.-diam hot gas unit, would be suitable for larger motors (Black Brant, Astrobee F, Sergeant, etc.). Each would be a self-contained system requiring no external umbilical or electrical interface with the payload.

3.1 Small Rocket System

The 9-in. system uses a 4.6 cu in. bottle pressurized with dry nitrogen to 3000 psi as the energy source. This bottle is 1.5 in. diam, 6.5 in. long, and incorporates a self-contained pyrotechnic-actuated valve that exhausts the gas through a crude nozzle. Taking into account gas cooling through the relatively inefficient nozzle, a total impulse of about 1.3 lb-sec could be expected. The bottle is mounted transversely at the vehicle/payload separation plane with its nozzle directed radially outward. Radial orientation is arbitrary as there is no way of predicting the vehicle radial orientation at initiation. Initiation of the valve is through the programmer of a standard Tomahawk yo-yo despin system. As an indicator of the upsetting force available, ignoring any restoring moment from the fins, the impulse applied could theoretically tumble the spent vehicle at about 10 deg/sec.

3.2 Large Rocket System

The 17-in. system uses a small solid-propellant rocket motor developed for the Minuteman system as the energy source. This motor, a 0.3 DS225, has a total impulse of 83.4 lb-sec, developing 229 lb thrust for 0.36 sec. The motor has a

maximum diameter of 2.3 in. and is 7.5 in. long. A separation/delta velocity module, 5.5 in. long and weighing 30 lb, was developed to be compatible with the standard Black Brant VC manacle-ring-separated recovery system. The tumble motor is flange mounted to the inside surface of the module, with the nozzle directed radially outward through a hole in the skin. Redundant three-switch, Raymond timers provide initiation capability for the despin, separation, and delta velocity functions. A pneumatic Airstroke actuator, pressurized to 100 psi, initially separates the 750-lb payload at about 2 m/sec. This actuator has an equivalent spring constant of 11,000 lb/ft with a 3-in. stroke, keeping the maximum acceleration under 5 G's. A comparison of the torque capability of this system vs the cold gas one, using the same assumption, indicates a spent BBV sould be tumbled at about 90 deg/sec and a spent Sergeant at about 25 deg/sec.

4. TEST RESULTS

4.1 Small Rocket System

The cold gas system was flown on two Paiute Tomahawk missions from White Sands Missile Range in September 1975. Payloads were 12-in. diam and weighed 420 lb. Each carried despin, separation, recovery, and attitude control systems. The sequence of events was as follows:

Time (sec)	Alt (km)	Q (psf)	Event
27	19.1	1300	Tomahawk burnout
58	58.9	6.0	Despin vehicle and payload to zero
64	65.7	2.3	Separate payload, initiate ACS
66	67.9	1.7	Initiate vehicle tumble system

Both payloads flew close to the predicted trajectory. For A10.304-1 at T + 60 sec, payload altitude difference (Δh) was +0.04 km from predicted and the range difference (Δr) from predicted was +2.60 km. At apogee, Δh was -0.45 km and Δr was +10.96 km. For A10.304-2 at T + 60 sec, Δh was -0.52 km and Δr was +2.80 km. At apogee, Δh was -0.81 km and Δr was +11.56 km from the predicted.

Five radars were assigned to each flight. In addition to the radar dictated by WSMR Missile Flight Safety, two radars were directed to track the payload beacon, and two others were directed to acquire track on the beacon but switch to skin mode

track of the rocket vehicle at the T + 64 sec separation time. Beacon track results were excellent, each radar providing full up and down data. Vehicle skin tracks were good until close to apogee where track was lost. These trajectories were easily completed by extrapolation. Data are presented from the best of each track, although there is good correlation within pairs.

Significant separation between payload and vehicle was achieved in both cases. Figure 1 shows altitude and range vs time of both bodies for flight A10. 304-1. At vehicle apogee, the rate of change of altitude from separation of the vehicle with respect to the payload was 0. 093 km/sec (305 ft/sec). Figure 2 shows the spacial separation between the payload and vehicle vs payload altitude. This indicates the separation at 100 km upleg was 3. 7 km, at apogee 14. 0 km, and at 100 km downleg 25. 4 km. Figure 3 is altitude and range vs time for flight A10. 304-2. At vehicle apogee the average altitude change was 0. 083 km/sec (270 ft/sec). Figure 4 shows the spatial separation for this flight; separation at 100 km upleg was 3. 4 km, at apogee it was 9. 9 km, and at 100 km downleg it was 15. 4 km.

Calculation of the average velocity for the 30-sec time period from +70 to +100 sec indicates that for A10. 304-1 the total velocity of the vehicle was retarded 0. 046 km/sec or 4. 8 percent compared to the payload total velocity. For A10. 304-2, the total velocity of the vehicle was retarded 0. 038 km/sec or 3. 9 percent compared to the payload total velocity. Figure 5 is a plan view (X, Y plane) of the -1 trajectory. This shows the vehicle took a 5. 25^{o} west track from the payload following separation. Figure 6 is an elevation view ($\sqrt{X^2 + Y^2}$, Z) of the -1 trajectory. This shows the average flight path angle for 10-sec increments, resulting in a 3. 8^{o} flatter angle for the vehicle in the 100- to 110-sec time period. Figure 7 is the plan view of the -2 trajectory showing the vehicle took a 1. 9^{o} east track from the payload. Figure 8 is the elevation view of the -2 trajectory showing a 4. 9^{o} flatter vehicle flight path angle at that time.

As indicated previously, it is not possible to predict the radial orientation of the vehicle at the instant of tumble initiation. Therefore, there is no control over the direction of any change in flight path angle.

4.2 Large Rocket System

The hot gas system was flown on a Sergeant mission from Poker Flat Research Range, Alaska, in April 1976. The payload was 17 in. diam and weighed 780 lb. A 40-in. -long transition from the payload to the 32-in. -diam Sergeant motor carried a despin and ballast, bringing payload gross weight to 1000 lb. Payload included the separation/delta velocity module and recovery and attitude control system. The sequence of events was as follows:

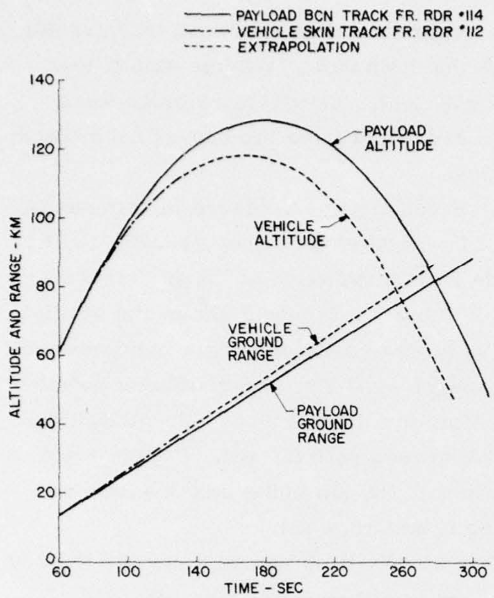

Figure 1. Payload/Vehicle Trajectory Comparison, AFGL Mission A10.304-1

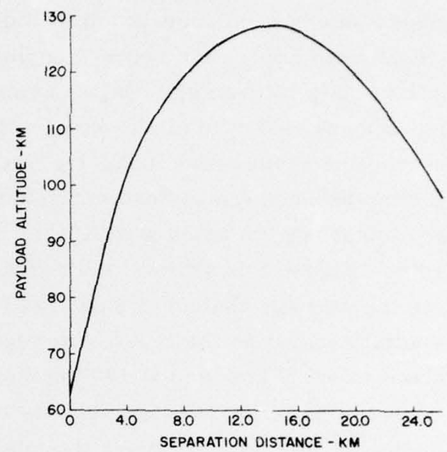

Figure 2. Payload/Vehicle Separation, AFGL Mission A10.304-1

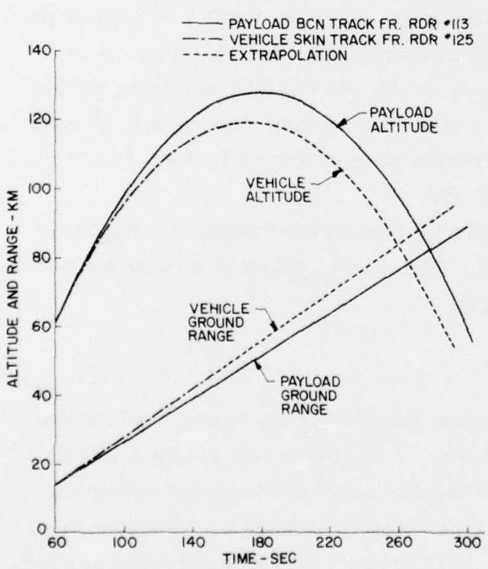

Figure 3. Payload/Vehicle Trajectory Comparison, AFGL Mission A10.304-2

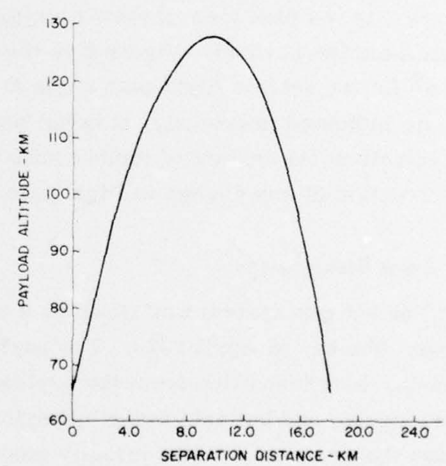

Figure 4. Payload/Vehicle Separation, AFGL Mission A10.304-2

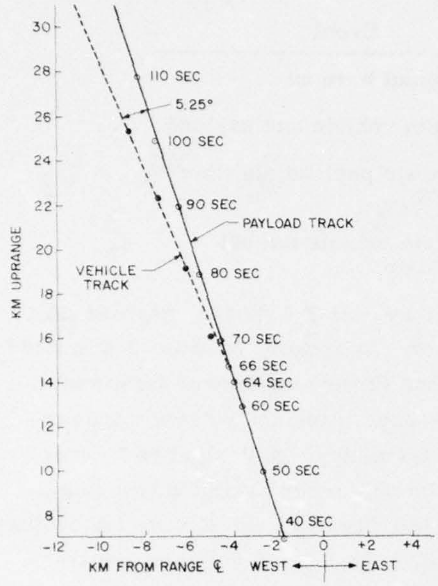

Figure 5. Trajectory Plan View, AFGL Mission A10.304-1

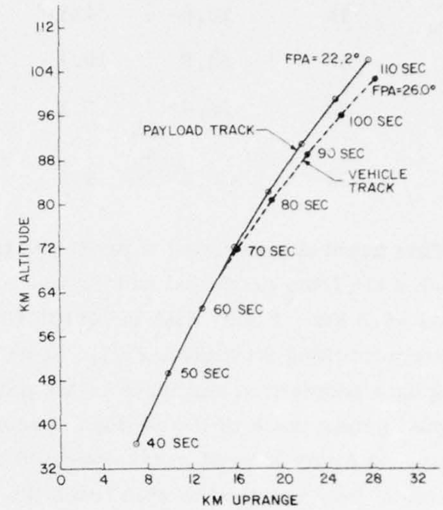

Figure 6. Trajectory Elevation View, AFGL Mission A10.304-1

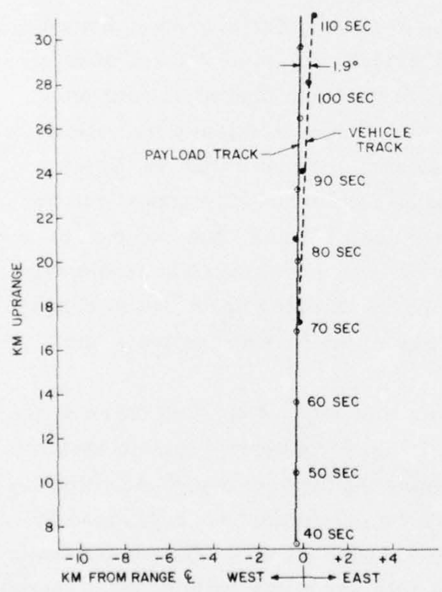

Figure 7. Trajectory Plan View, AFGL Mission A10.304-2

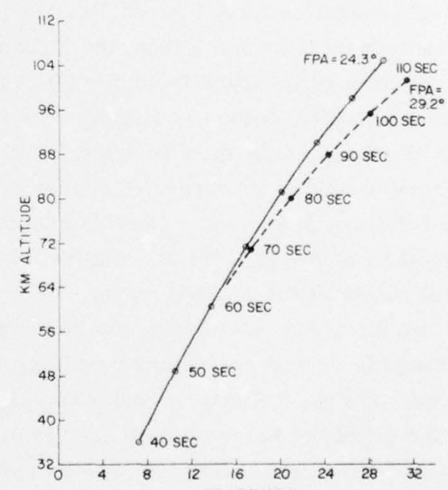

Figure 8. Trajectory Elevation View, AFGL Mission A10.304-2

Time (sec)	Alt (km)	Q (psf)	Event
36	29.0	451	Sergeant burnout
56	53.9	10.1	Despin vehicle and payload
60	58.4	5.6	Separate payload, initiate ACS
62	60.5	4.1	Initiate vehicle tumble system

This payload also flew the predicted trajectory. At T + 60 sec, payload Δh was -0.2 km from predicted and Δr was -1.7 km. At apogee, Δh was +3.3 km and Δr was -6.5 km. Poker Flat Research Range has limited equipment for simultaneously tracking multiple targets. Two tone-range tracking systems were providing data acquisition and track of the payload telemetry. A Verlort radar was assigned prime track of the payload beacon. The only other available tracking system, an Army X Band radar operated by WSMR Atmospheric Science Laboratory personnel, was assigned to skin track the vehicle. An L Band meteorological-balloon-type transmitter was installed in the delta velocity module to assist the X Band system by providing tracker elevation and azimuth information from an adjacent GMD. Tone-range tracking of the payload was excellent, providing complete up and down data. Due to technical difficulties the Verlort radar did not acquire solid track of the beacon until T + 150 sec. The X-Band radar also experienced technical difficulties, not acquiring lock until T + 65.8 sec, almost 6 sec after payload separation from the vehicle. Reduction of this data proved discouraging. The altitude vs time track from the X-Band system shows excellent correlation with the tone-range track from T + 66 to T + 141 sec. Ground range vs time for the corresponding period is slightly less for the X-Band track, but appears to be more of a fixed offset than the expected diverging case. The X-Band system looses accuracy beyond slant ranges of approximately 135 km, resulting in unusable data from 155 through 255 sec. Lock is reacquired on the downleg and again is almost identical to tone-range track. Figure 9 is the plot of the tone-range track and typical points of the X-Band track.

Two different conclusions can be drawn from this data. One, that there was no change in vehicle trajectory resulting from firing of the vehicle tumble system, or, two, that the X-Band tracker was skin tracking the separated payload rather than the expended Sergeant motor. Firing of the tumble motor was confirmed by ground cameras recording the payload penetration of the aurora. Based on results of the two earlier flights, some change in flight path angle was anticipated. Therefore, it is the parochial viewpoint of the author that the data presented are individual tracks of the same body, the separated payload.

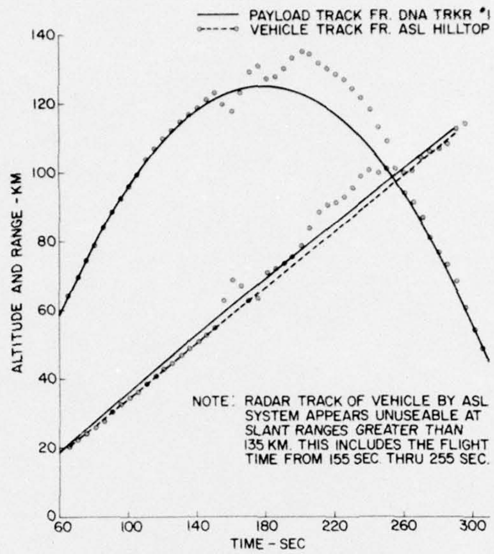

Figure 9. Payload/Vehicle Trajectory Comparison, AFGL/DNS Mission IC 630.02-1A

5. CONCLUSIONS AND RECOMMENDATIONS

A vehicle tumble system to enhance deceleration and direct the vehicle onto a new flight path angle can be an effective means of accomplishing large spatial separation between a separated payload and the spent final stage rocket motor. This delta velocity system can be simple, inexpensive, and operationally isolated from the payload, assuring no degradation of reliability of the prime mission.

Much more flight data are necessary to establish the parameters necessary for predicting this spacial separation. It has been shown that a system as simple as the addition of a small pressure bottle that is activated by existing flight programmers can accomplish this end. Tracking of separated vehicles should be attempted whenever possible, even when no delta velocity system is employed, in order to build a data base.